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JAN 77 L I KNAB, R C MOODY, W W SANDERS

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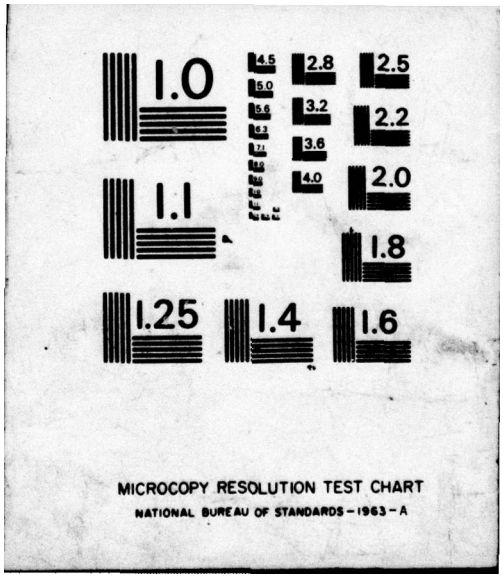
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TECHNICAL REPORT M-198
January 1977
AFCS Design Parameters for T/O Material Applications

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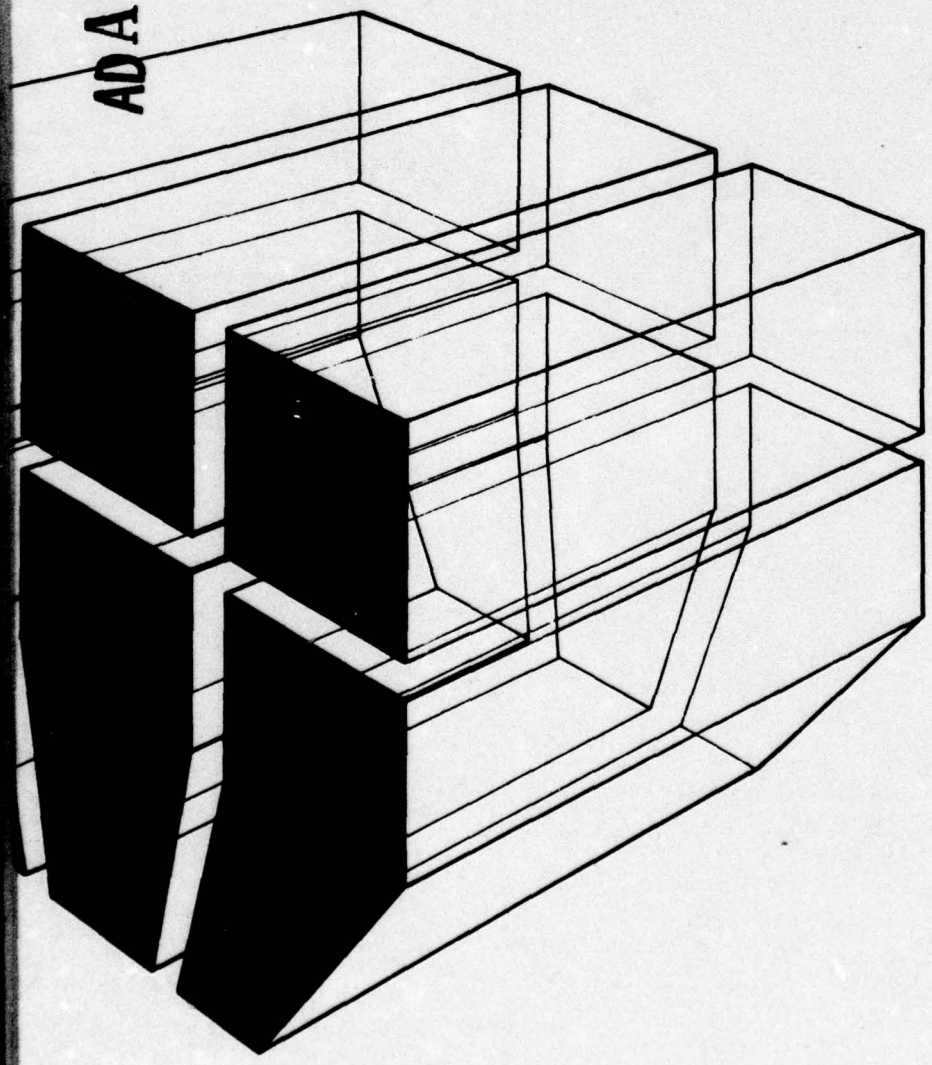
DESIGN CRITERIA FOR THEATER OF OPERATIONS GLUED-LAMINATED TIMBER HIGHWAY BRIDGES VOLUME I



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This report presents structural design criteria recommendations for theater of operations (T/O) temporary glued-laminated timber highway bridges. The report consists of two volumes: Volume I provides the design criteria, procedures, and material specifications, and Volume II contains the development of and justification for the criteria in Volume I.

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State-of-the-art methodologies were used to develop the criteria, which are based on modifications to existing military and permanent criteria. Use of the criteria by engineers in bridge design offices should result in T/O bridges that have adequate safety and perform satisfactorily.

Material weight of glued-laminated timber stringers in T/O bridges designed using the recommended criteria, typically will be about 15 percent less than when designed using permanent bridge criteria.

FOREWORD

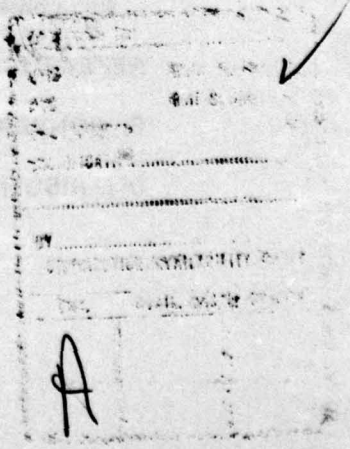
This study was conducted for the Directorate of Facilities Engineering, Office of the Chief of Engineers (OCE) under Project 4A763734DT34, "Development of Engineer Support to the Field Army"; Task 04, "Base Development"; Work Unit 002, "AFCS Design Parameters for T/O Material Applications."

Mr. R. H. Barnard was the OCE Technical Monitor.

The research was conducted by the Construction Materials Branch (MSC) of the Materials and Science Division (MS), U.S. Army Construction Engineering Research Laboratory (CERL). Dr. L. I. Knab was Principal Investigator for the project. Mr. P. A. Howdyshell is Chief of MSC and Dr. G. R. Williamson is Chief of MS.

Contractors contributing to the study were R. C. Moody of the U.S. Department of Agriculture Forest Service, Forest Products Laboratory, Madison, WI and W. W. Sanders, Jr. and H. A. Elleby of the Iowa State University Department of Civil Engineering, Ames, IA.

COL J. E. Hays is Commander and Director of CERL and Dr. L. R. Shaffer is Technical Director.



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RECOMMENDED DESIGN CRITERIA FOR GLUED-LAMINATED TIMBER HIGHWAY BRIDGES IN THEATERS OF OPERATION

1 INTRODUCTION

Background

Engineer troop units in the theater of operations (T/O) are assigned diverse construction missions which often have critical completion date requirements. Many of these missions involve erection or assembly of standard prefabricated components such as those available for buildings and tactical bridges, while others require construction using conventional materials and components.

The Army Facilities Components System (AFCS) contains standard designs for many structures that T/O troop units may be required to construct. The AFCS publication TM 5-302,[1] and its related logistical references TM 5-301[2] and TM 5-303,[3] contain many standard structural designs using both standard and prefabricated components, along with bills of materials and construction practice guidance. These manuals greatly reduce the planning and design effort required to complete a construction assignment.

However, design criteria for military bridges using glued-laminated timber are currently unavailable. Since the design life of T/O structures is typically from 2 to 5 years, use of civilian structural design codes, which are generally based on a 50- to 75-year design life and relatively high levels of reliability, can result in unnecessarily conservative and uneconomical designs for the limited performance needs of T/O structures.

Objective

The objective of this study is to develop design criteria recommendations for glued-laminated timber members in T/O highway bridges subjected to dead plus static live loads. The types of glued-laminated timber to be considered are those specified by American Institute of Timber Construction (AITC) Specification 117-74[4] and Product Standard (PS) 56-73,[5] which cover glued-laminated timber fabricated from Douglas fir, Western larch, Southern pine, and California redwood.

Approach

Appropriate reliability models were developed to analyze and evaluate the safety levels and consistency of existing permanent structural design criteria for glued-laminated timber bridge members. The models were then used to develop recommended T/O bridge design criteria for glued-laminated timber members for the dead plus live static load case.

Chapter 2 summarizes the development of the design criteria (the development and justifications for the criteria are detailed in Appendices A through E of Volume II). Chapter 3 presents the recommended design criteria, and Chapter 4 provides a design example. Chapter 5 presents the conclusions and recommendations.

2 SUMMARY OF DESIGN CRITERIA DEVELOPMENT

This report presents a rational basis for developing consistent design criteria for short-life structures. "Consistent" means that the probability or chance of reaching a limit state (limit state probability) of a structural member is compatible with the other limit state probabilities of that member or other members.

Member-resistance and structural loading data were combined to determine existing and recommended limit state probabilities and their corresponding safety index values. First order reliability theory and best estimates of central tendency (average values) coupled with measures of dispersion (coefficients of variation) of the resistance and load were used to compute the safety index values. These safety index values were computed for permanent and temporary structural elements and used as guides in determining recommended allowable stresses for the static failure mode. Recommended criteria for temporary bridges were determined to

[1] *Army Facilities Components System (AFCS)—Design*, TM 5-302 (Department of the Army, 1973).

[2] *Army Facilities Components System (AFCS)—Planning*, TM 5-301 (Department of the Army, 1973).

[3] *Army Facilities Components System (AFCS) Logistic Data and Bills of Materials*, TM 5-303 (Department of the Army, 1973).

[4] *Standard Specifications for Structural Glued Laminated Timber of Douglas Fir, Western Larch, Southern Pine, and California Redwood*, AITC 117-74 (American Institute of Timber Construction [AITC], 1974).

[5] *Voluntary Product Standard PS 56-73 for Structural Glued Laminated Timber* (AITC, 1973).

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yield safety index values which will provide adequate safety relative to the safety levels and performance of permanent bridges, while reflecting the bridges' temporary nature.

It was assumed in the criteria development that adequate fabrication, assembly, and erection procedures are used. Special provisions and criteria are recommended when lower quality fabrication, assembly, and erection practices are likely to occur.

Stringer weight savings of about 15 percent result from using the recommended T/O bridge design criteria rather than using the permanent bridge allowable stresses with the design procedures in Chapter 3.

3 RECOMMENDED DESIGN CRITERIA FOR AFCS BRIDGES

Scope

The following criteria are recommended for use in designing temporary T/O bridges using glued-laminated timber. Temporary bridges have design lives of 2 to 5 years (bridges whose failure would have unusually severe consequences are not considered temporary, even though their design lives may be 2 to 5 years). The maximum deviation from these criteria shall not exceed 2 percent (on the unconservative side) of the indicated design requirements.

The following criteria are based on AITC 117-74, PS 56-73, and the 1973 *National Design Specification (NDS) for Stress Grade Lumber and Its Fastenings,*[6] except as modified herein. The criteria apply to highway bridges only; they do not apply to railroad bridges.

Safety, Savings, and Cost Effectiveness

In the past, increased allowable stresses for static loading have been permitted for temporary steel stringer bridges.[7] The safety levels corresponding to the allowable stresses and/or design procedures for temporary glued-laminated stringer bridges were evaluated and used to determine acceptable design criteria and procedures which reflect the temporary nature of T/O bridges. The safety levels corresponding to the recommended criteria for T/O bridges loaded with their normal or maximum loads are comparable to or exceed those corresponding to permanent civilian bridges loaded with their maximum loads. However, the safety levels corresponding to the recommended criteria for T/O bridges loaded with their normal or maximum loads are below those corresponding to permanent bridges loaded with their normal loads. In summary, the recommended criteria should result in acceptably safe temporary bridges compared with current permanent civilian bridges loaded with their maximum loads.

This discussion of safety is based on the assumption of adequate fabrication, assembly, and erection practices; the safety of a bridge can be reduced significantly by low quality fabrication, assembly, and erection practices (see the **Fabrication, Assembly, Erection, and Handling** section of this chapter).

Material weight of glued-laminated timber stringers in T/O bridges designed using the recommended criteria will typically be about 15 percent less than when designed using permanent bridge allowable stresses with the procedures recommended in this chapter.

Use of the recommended criteria rather than the permanent criteria to prevent static failure will be cost effective if the material, transportation, labor, and storage cost savings exceed the cost of implementing the criteria (see the **Implementation** section of this chapter).

Use of the recommended criteria appears reasonable, provided that the temporary steel and timber bridges used in the past have been acceptably safe and have performed satisfactorily. The decision to use the recommended criteria is to be made by the AFCS Office at the Office of the Chief of Engineers (DAEN-FEE-A).

Implementation

The recommended criteria are based on modifications to existing (AITC 117-74 and 1973 NDS) allowable stresses for permanent structures. The recommended criteria require use of the military design loads and procedures (as opposed to allowable stresses) given in TM 5-312 and modified herein. Hence, the recommended criteria are intended for use by bridge design offices, and not by combat engineers in the field. The criteria "package" required

[6] *National Design Specification for Stress Grade Lumber and Its Fastenings* (National Forest Products Association, 1973).

[7] *Military Fixed Bridges,* TM 5-312 (Department of the Army, December 1968), with changes 1 and 2.

by a bridge design office would consist of these criteria (Chapter 3), which in turn require the use of modified TM 5-312 design loads and procedures and the modified AITC 117-74 and 1973 NDS allowable stresses.

Fabrication, Assembly, Erection, and Handling

The recommended criteria are based on the assumption that fabrication, assembly, and erection quality and tolerances are comparable to those used in U.S. permanent construction. The recommended allowable stresses shall be reduced accordingly for low quality fabrication, assembly, or erection. Fabrication, assembly, and erection shall be in accordance with AITC 117-74 and the AITC *Timber Construction Manual.*[6] Necessary precautions, including provision of adequate support and bracing to protect against buckling and other erection problems, shall be taken during erection.

Handling precautions shall be taken, especially for laminations which will be subjected to tension* during service. Notching the bottom of stringer ends (e.g., to lower the elevation of the roadway) shall not be permitted.

Serviceability

Because the criteria recommendations are based on limit state strength only, serviceability requirements, including deflection, are *not* covered by the criteria; they shall be imposed as judged necessary.

Preservative Treatments

In warm, moist areas, preservative treatment may be necessary to insure a 5-year life for members in ground contact, e.g., abutments, pilings, etc. If preservative treatment is not feasible, consideration should be given to specifying all heartwood decay-resistant species.**

Loads, Moments, and Forces†

The recommended criteria apply to the dead plus live load case (vehicle plus payload weight). Other loads, including wind, water, ice, and earthquake, are not covered.

The procedures given in TM 5-312 for determining the design loads and the moments and forces used in the design of bridge members and fastenings shall be used, except as modified herein.

The two load cases used in the design process—the *normal* vehicle crossing load case and the *caution* crossing load case—are described in Table 4-3 of TM 5-312. Normal crossings are convoy(s) consisting of vehicles not exceeding the posted bridge class. A caution crossing consists of a single line of vehicles crossing a one- or two-lane bridge on the bridge centerline. Each vehicle is spaced at 150 ft* or more and shall not be more than 1.25 times the normal posted bridge class. Additional details are given in Section IV, Chapter 4, of TM 5-312 and Paragraph 2-54 of FM 5-36.[9]

The current procedure in TM 5-312 proportions all members, fastenings, and connections on the basis of the normal class loading. The following recommended procedure, however, requires that they be proportioned on the basis of either the normal or caution load cases, as specified.

Flexural Members and Flexural Splices—Designing for Bending or Lateral Buckling in Stringers

The live load moments corresponding to normal class crossings found in Appendix D of TM 5-312 shall be used to proportion the flexural members or flexural splices for bending and lateral buckling.

The current procedure for stringer design given in Paragraph 6-5 of TM 5-312 shall be used, except that the recommended formulas in Table 1 shall be used to determine the effective number of stringers.

Shear in Stringers, Bearing Forces at Stringer Ends, and Forces in Stringer End Connection Fastenings

The live load shear force in stringers, bearing forces at ends of stringers, and forces in stringer end connection fastenings shall be determined by using the larger force resulting from the normal or caution

[6] *Timber Construction Manual,* 2nd ed. (AITC, 1974).

*Typically, the bottom laminations in stringers.

**For more information see "Decay Resistance," *Wood Handbook: Wood as an Engineering Material,* Forest Service Agricultural Handbook No. 72 (Department of Agriculture, Forest Products Laboratory, 1974).

†In certain cases, unrealistically low loads, moments, and forces can result if the current procedures in TM 5-312 are used.

*SI conversion factors for all units of measurement used in this report are given at the end of the report.

[9] *Route Reconnaissance and Classification,* FM 5-36 (Department of the Army, May 1965).

Table 1

Recommended Equations and Current TM 5-312 Equations for Determining the Effective Number of Stringers

Current TM 5-312 Equations	Recommended Equations
Single lane: $N_1 = \frac{5}{S_S} + 1$ (Eq 6-7a)	Single lane: $N_1 = c\left[\frac{5}{S_S} + 1\right]$
Two lanes: $N_2 = \frac{3}{8} N_S$ or $N_2 = N_1$ (Eq 6-7b)	Two lanes: $N_2 = c\left[\frac{3}{8} N_S\right]$ or $N_2 = N_1$
whichever is smaller	whichever is smaller

where N_1 = effective number of stringers for single-lane bridges
S_S = center-to-center stringer spacing in feet
N_S = number of stringers
N_2 = effective number of stringers for two-lane bridges
c = reduction factor given in Table 2

Table 2

Values of Reduction Factor c* Used in Recommended Formulas (Table 1) for Determining the Effective Number of Stringers

Bridge Deck Type	Ratio of Bridge Floor Width (out-to-out) to Bridge Span Length (W/L)	
	W/L ≤ 1.0	W/L > 1.0
Glued-laminated timber or concrete	1.0	0.75
Nailed-laminated timber, plank, or multiple-layered	0.90	0.70

*The factor c accounts for the reduction in lateral load distribution when using nailed-laminated timber, plank, or multiple-layered decks and/or bridges which are very wide compared to their span length.

crossing load cases. The shear for single-lane bridges is based on the caution load case; for two-lane bridges it is based on either the normal load case or, if larger, the caution load case. The following procedure (revised Paragraph 6-6, TM 5-312) shall be used to determine the shear force in stringers, the bearing forces at stringer ends, and the forces in stringer end connection fastenings.

6-6.* Shear Check (Shear Design)

c. *Glued-Laminated Timber Stringer Bridges*

Compared to steel stringers, glued-laminated timber stringers are relatively lower in horizontal shear strength. Thus, shear can be critical in glued-laminated timber stringers, and the horizontal shear stress often controls the allowable design load, particularly for short spans.

*Paragraph 6-6b shall be retitled *Solid-Sawn Timber Stringer Bridges.*

(1) *Dead Load Shear.* The dead load shear per stringer is determined as for a steel stringer bridge using

$$v_{DL} = \frac{V_{DL}}{N_S} \quad \text{(Equation 6-12)}$$

(2) *Live Load Shear.*

(a) *Effective shear per stringer, v'_{LL}, for glued-laminated timber stringers.* The effective live load shear per stringer, v'_{LL}, must account for the shear per stringer due to loads near the support as well as loads out on the span. It can be assumed that the wheel or track loads which are at or near a support will go directly into the stringer (with the deck assumed to act as a series of simple beams) and the loads which are out on the span will be distributed laterally in a manner similar to moment. The effective live load shear per stringer v'_{LL} in kips shall be determined from Table 3.

(b) *Design live load shear per stringer, v_{LL}, for glued-laminated timber stringers.* Tests with timber beams indicate that the shear failure will occur when a concentrated load is at some constant distance from the support, rather than when the load is just off the support, the location that produces maximum shear. This is caused by the concentrated load tending to compress the fibers, thus increasing the horizontal shear strength. When the load is moved off the support a distance of about the depth of the stringer, the optimum condition for shear failure exists. Thus, the value of the effective live load shear per stringer, v'_{LL}, should be reduced accordingly. The design live load shear per stringer, v_{LL}, in kips, is:

Table 3

Value of Effective Live Load Shear Force per Stringer, v'_{LL}

	v'_{LL} for Single Lane,* kips	v'_{LL} for Double Lane,** kips
Wheeled vehicle	$1.25[(0.5+\frac{S_s}{32})V_A+(\frac{V_{LL_W}-V_A}{N_1})]$	$(\frac{S_s-2}{S_s})V_A+(\frac{V_{LL_W}-V_A}{N_2})$
Tracked vehicle	$1.25(\frac{V_{LL_T}}{2})$	$(\frac{S_s-2}{S_s})V_{LL_T}$

where: V_{LL_W} = wheeled vehicle shear in kips as given in Appendices D-4 and D-7† of TM 5-312

V_{LL_T} = tracked vehicle shear in kips as given in Appendices D-5 and D-7† of TM 5-312

V_A = the heaviest axle load in kips as given in column 3† of Appendix D-1 of TM 5-312

S_s = stringer spacing in ft

N_1 = effective number of stringers for single lane given in Table 1

N_2 = effective number of stringers for double lane given in Table 1.

*The coefficient of 1.25 is used to adjust shear from normal crossing case to caution crossing case.
**For the double-lane case, v'_{LL} shall be computed for both single and double lanes and the larger value of v'_{LL} shall be used.
†Entries in Appendix D-7 and column 3 of Appendix D-1 are given in tons and must be converted to kips.

$$v_{LL}=(\frac{L-d}{L})v'_{LL}, \text{ but not less than } 0.75\,v'_{LL}$$

(Revised Equation 6-17)

where v_{LL} = design live load shear per stringer in kips
L = bridge span in ft
d = depth of stringer in ft
v'_{LL} = effective live load shear per stringer from Table 3.

(3) *Total Shear Per Stringer.* .The total design shear, v, for a glued-laminated timber stringer is:

$$v=v_{DL}+v_{LL}$$

where v = total design shear per stringer in kips
v_{DL} = dead load shear per stringer in kips
v_{LL} = design live load shear per stringer in kips.

The rest of the shear design procedure shall be the same as that given in subparagraphs (4) and (5) of Paragraph 6-6b, *Timber Stringer Bridges* of TM 5-312.

Columns, Compression and Tension Members, and Their Associated Fastenings and Connections

The forces in compression or tension members and their associated fastenings and connections shall be the larger of the forces produced by the normal or caution crossing load cases.

Impact

The procedure to account for impact (no increase) given in TM 5-312 shall be followed.

Allowable Stresses—Members

The allowable stress for members in temporary T/O bridges shall be found from

$$f=MF \qquad \text{[Eq 1]}$$

where f = allowable stress for members in temporary bridges
M = modification factor found in Table 4
F = AITC 117-74 allowable stresses for members for the dead plus live load case for 10 years of continuous or cumulative

Table 4

Recommended Modification Factor M

Resistance*	Value of M
Bending	1.35
Shear	1.15
Compression parallel to grain**	1.15
Compression perpendicular to grain	1.15
Column buckling	1.00
Tension parallel to grain	0.80

*Appropriate member moments and forces shall be determined as specified in the **Loads, Moments, and Forces** section.

**Applies to fully braced columns only, i.e., when buckling cannot occur.

loading; F shall include all NDS modifications of stresses (except load duration) including moisture content, size effect (for bending), lateral stability (for bending), buckling (compression members), and bearing.

Depending on the application, bridge stringers treated with an oil-base preservative and having a waterproof deck may be designed with dry-use stresses for bending and shear. However, wet-use stresses shall always be used for compression perpendicular to grain.

Criteria for Fastenings and Joints, and Other Criteria Not Covered Herein

Criteria for fastenings and joints, and other criteria not covered herein, shall be as specified by NDS for permanent bridges; a load duration of 10 years of continuous or cumulative loading shall be used.

Criteria for Bridges Having Unusually High Consequences of Failure

For bridges whose failure would have unusually severe consequences, the AITC 117-74 allowable stresses for 10 years of continuous or cumulative loading (i.e., for permanent bridges) shall be used for members, except that 70 percent of the AITC 117-74 allowable stress for tension* shall be used. Criteria for fastenings and joints and all other criteria (except allowable stresses for members) shall be as specified by NDS for permanent bridges; a load duration of 10 years of continuous or cumulative loading shall be used. Recommendations given in the **Loads, Moments, and Forces** section of this chapter shall be used.**

Modulus of Elasticity†

Modulus of elasticity values for deflection checks and column design shall be taken from AITC 117-74.

4 DESIGN EXAMPLE

The following example of the design of glued-laminated stringers for an AFCS bridge is based on the criteria given in Chapter 3. Additional references[10] commonly used in glued-laminated timber design for permanent structures are suggested.

Design of Glued-Laminated Timber Stringer Bridge

Design class 50, two-lane bridge, glued-laminated stringers, nailed-laminated timber deck, single 60-ft span, stringer timber: Southern pine 24 F-3 combination, dry condition of use.

*Refers to axial tension parallel to grain and not to tension due to bending.

**In certain cases, unrealistically low loads, moments, and forces can result if the current procedures in TM 5-312 are used.

†This section applies to temporary bridges and bridges having unusually high consequences of failure.

[10] *Glulam Bridge Systems Plans* (AITC, 1974); *Timber Construction Manual*, 2nd ed. (AITC, 1974); *National Design Specification for Stress Grade Lumber and Its Fastenings* (National Forest Products Association, 1973); and *Standard Specifications for Highway Bridges* (American Association of State Highway and Transportation Officials, 1973).

Procedure	*Remarks* (References refer to TM 5-312 unless otherwise noted)

1. *Design Loads (60-ft span)*

   a. *Dead Load*

$$W'_{DL} = X + L\,(Y + ZC)$$ Equation 6-1

$$W'_{DL} = 500 + 60\,[7 + 0.4(50)]$$ Table 6-1

$$W'_{DL} = 2120 \text{ lb/ft} = 2.12 \text{ kips/ft}$$

$$M_{DL} = \frac{W'_{DL}L^2}{8} = \frac{(2.12)(60)^2}{8}$$ Equation 6-2

$$= 954 \text{ kip-ft}$$

$$V_{DL} = \frac{W'_{DL}L}{2} = \frac{2.12(60)}{2}$$ Equation 6-3

$$= 63.6 \text{ kips}$$

   b. *Live Load*

$M_{LL_W} = 1235$ kip-ft — Appendix D-6

$M_{LL_T} = 1338$ kip-ft ← Controls — Appendix D-6

$V_{LL_W} = 89.5$ kips — Appendix D-7

$V_{LL_T} = 89.2$ kips — Appendix D-7

2. *Stringer Selection*

   a. *Effective Stringers*

For a class 50 two-lane bridge, the minimum width is 24 ft 0 in. Maximum stringer spacing is 6 ft 0 in. — Table 6-2

The minimum number of stringers (N_s) is

$$N_s = \frac{W_R}{S_s} + 1 = \frac{24.0}{6.0} + 1 = 5$$ Equation 6-5a

The effective number of stringers for a two-lane bridge (N_2) is

$N_2 = c[\frac{3}{8} N_s]$ or $N_2 = N_1$

whichever is smaller

Table 1 in Chapter 3 of this report.

$N_1 = c[\frac{5}{S_s} + 1]$

Table 1 in Chapter 3 of this report.

$c = 0.90$

Table 2 in Chapter 3 of this report. The reduction factor c corresponds to $W/L < 1.0$ and a nailed-laminated timber deck.

$N_1 = 0.90[\frac{5}{6.0} + 1] = 1.65$

$N_2 = 0.90[\frac{3}{8}(5)] = 1.69$ or

$N_2 = N_1 = 1.65$

Use smaller of N_1 or N_2

Therefore: $N_2 = 1.65$

b. *Design Moment,* m

$m = m_{DL} + m_{LL}$

Equation 6-9a

$m = \frac{M_{DL}}{N_s} + \frac{M_{LL}}{N_2}$

$m = \frac{954}{5} + \frac{1338}{1.65}$

$= 190.8 + 810.9$

$m = 1001.7$ kip-ft

c. *Required Section Modulus*

$S_r = \frac{m(12)}{f_b}$

Equation 6-10

Allowable bending stress, f_b

$f_b = MF_b$

Equation 1 in Chapter 3 of this report where M = modification factor in Table 4 and F_b = allowable AITC 117-74 bending stress (assuming adequate lateral support).

$M = 1.35$

$F_b = C_F(2400)$

F_b for Southern pine, 24F-3 combination, dry is:
$F_b = C_F(2400)$

$C_F = (12/d)^{1/9}$

C_F = size effect factor given in Section 903-F NDS.

d = depth of member, in.

To obtain an estimate of F_b and f_b assume

$C_F = 0.85$

Then $f_b = (1.35)(0.85)(2400)$

$= 2754$ psi $= 2.75$ ksi

The required section modulus based on f_b = 2.75 ksi is

$$S_r = \frac{m(12)}{f_b} = \frac{(1001.7)(12)}{2.75}$$

Equation 6-10

$= 4371$ in.^{3}

Trial Section:
b(width) = 10.75 in. (actual dimension)
d(depth) = 49.5 in. (actual dimension)

Also see table in AITC 117-74 titled "Structural Glued-Laminated Timber Section Properties"

$C_F = (12/49.5)^{1/9} = 0.85$

Therefore $f_b = 2.75$ ksi is correct
and $S_r = 4371$ in.^{3}

$$S = \frac{bd^2}{6} = \frac{(10.75)(49.5)^2}{6}$$

$= 4390$ in.^{3}

$S > S_r$

Therefore, trial section is adequate for bending, assuming adequate lateral support

3. *Shear Check*

a. *Dead Load Shear*

$$v_{LL} = \frac{V_{DL}}{N_s} = \frac{63.6 \text{ kips}}{5}$$

Equation 6-12

$= 12.7$ kips

b. *Live Load Shear*

$v_{LL} = (\frac{L-d}{L})v'_{LL}$, but not less than $0.75\, v'_{LL}$ — Equation 6-17 of TM 5-312 as revised in Chapter 3 of this report.

v'_{LL}, *Wheeled Vehicle, Single Lane:*

$v'_{LL} = 1.25[(0.5 + \frac{S_s}{32})V_A + (\frac{V_{LL_W} - V_A}{N_1})]$ — Table 3, Chapter 3 of this report.

$S_s = 6.0$ ft

$V_A = 40$ kips — Appendix D-1, Column 3

$V_{LL_W} = 89.5$ kips

$N_1 = 1.65$

$v'_{LL} = 1.25[(0.5 + \frac{6.0}{32})40 + (\frac{89.5 - 40}{1.65})]$

$= 71.9$ kips

v'_{LL}, *Wheeled Vehicle, Double Lane:*

$v'_{LL} = (\frac{S_s - 2}{S_s})V_A + (\frac{V_{LL_W} - V_A}{N_2})$ — Table 3, Chapter 3 of this report.

$N_2 = 1.65$

$v'_{LL} = (\frac{6 - 2}{6})40 + (\frac{89.5 - 40}{1.65})$

$= 56.7$ kips

v'_{LL}, *Tracked Vehicle, Single Lane:*

$v'_{LL} = 1.25\,(\frac{V_{LL_T}}{2})$ — Table 3, Chapter 3 of this report.

$V_{LL_T} = 89.2$ kips

$v'_{LL} = 1.25\,(\frac{89.2}{2}) = 55.8$ kips

v'_{LL}, *Tracked Vehicle, Double Lane:*

$v'_{LL} = (\frac{S_s - 2}{S_s})V_{LL_T}$ — Table 3, Chapter 3 of this report.

$S_s = 6.0$ ft

$v'_{LL} = (\frac{6-2}{6})89.2 = 59.5$ kips

Use largest v'_{LL} for single and double lanes and wheeled and tracked vehicles; — Table 3, Chapter 3 of this report.

Therefore $v'_{LL} = 71.9$ kips

The live load shear then becomes:

$v_{LL} = (\frac{60-(49.5/12)}{60})71.9$ — Equation 6-17 of TM 5-312 as revised in Chapter 3 of this report.

but not less than 0.75(71.9)

$v_{LL} = 0.93(71.9) = 67.0$ kips

and 67.0 kips > 0.75(71.9) kips

Therefore, $v_{LL} = 67.0$ kips

c. *Total Design Shear*

$v = v_{DL} + v_{LL} = 12.7 + 67.0$ — Chapter 3 of this report.

$= 79.7$ kips

d. *Effective Shear Area*

$A_{v_r} = \frac{v}{f_v}$ — Equation 6-19

$f_v = MF_v$ — Equation 1, Chapter 3 of this report.

$M = 1.15$ — Table 4, Chapter 3 of this report.

For Southern pine, combination 24F-3

$F_v = 200$ psi — Allowable AITC 117-74 shear stress, $F_v = 200$ psi

$f_v = 1.15(200) = 230$ psi

$= 0.230$ ksi

$A_{v_r} = \frac{79.7}{0.230} = 346$ sq in.

A_v of b = 10.75 in.,

d = 49.5 in. section:

$A_v = \frac{2}{3}bd$ — Equation 6-20

$$A_v = \frac{2}{3}(10.75)(49.5) = 354.75 \text{ sq in.}$$

$A_v > A_{v_r}$ Shear O.K.

4. The deck must be designed and the actual dead load versus the assumed dead load checked; appropriate changes in section modulus and shear area, if necessary, must then be made. The deflection and lateral bracing must be checked, the fastenings and joints must be designed, and the bearing must be checked.

5 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Design criteria, procedures, and material specifications developed using state-of-the-art methodologies should result in adequate safety and performance for T/O glued-laminated timber stringer highway bridges. (Volume II presents the development and justification of the criteria.)

2. Bridge stringer material weight savings of about 15 percent result when using the recommended T/O bridge design criteria rather than using permanent bridge allowable stresses with the design procedures recommended in Chapter 3.

3. The criteria, design procedures, and material specifications are given in Chapter 3 for AFCS bridges. In Chapter 3, modified design loads and procedures given in TM 5-312 and modified AITC 117-74 allowable stresses are recommended. The recommendations in Chapter 3 for AFCS bridges are intended to be used by engineers in bridge design offices, and not by combat engineers in the field.

Recommendations

1. The design criteria, procedures, and material specifications given in Chapter 3 should be considered for use in the design of AFCS T/O bridges.

2. Consideration should be given to the development of procedures, criteria, and material specifications for the design of glued-laminated timber decks for T/O glued-laminated timber stringer bridges.

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SI CONVERSION FACTORS

1 ft = 0.3048 m	1 kip-ft = 1.3558 kNm
1 ft-lb = 1.3558 Nm	1 ksi = 0.69 kN/cm^2
1 in. = 2.54 cm	1 sq in. = 6.4516 cm^2
1 kip = 4.448 kN	(°F −32) 5/9 = °C

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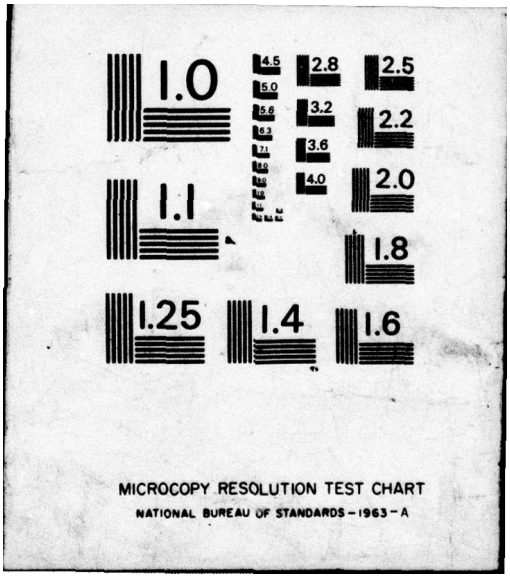
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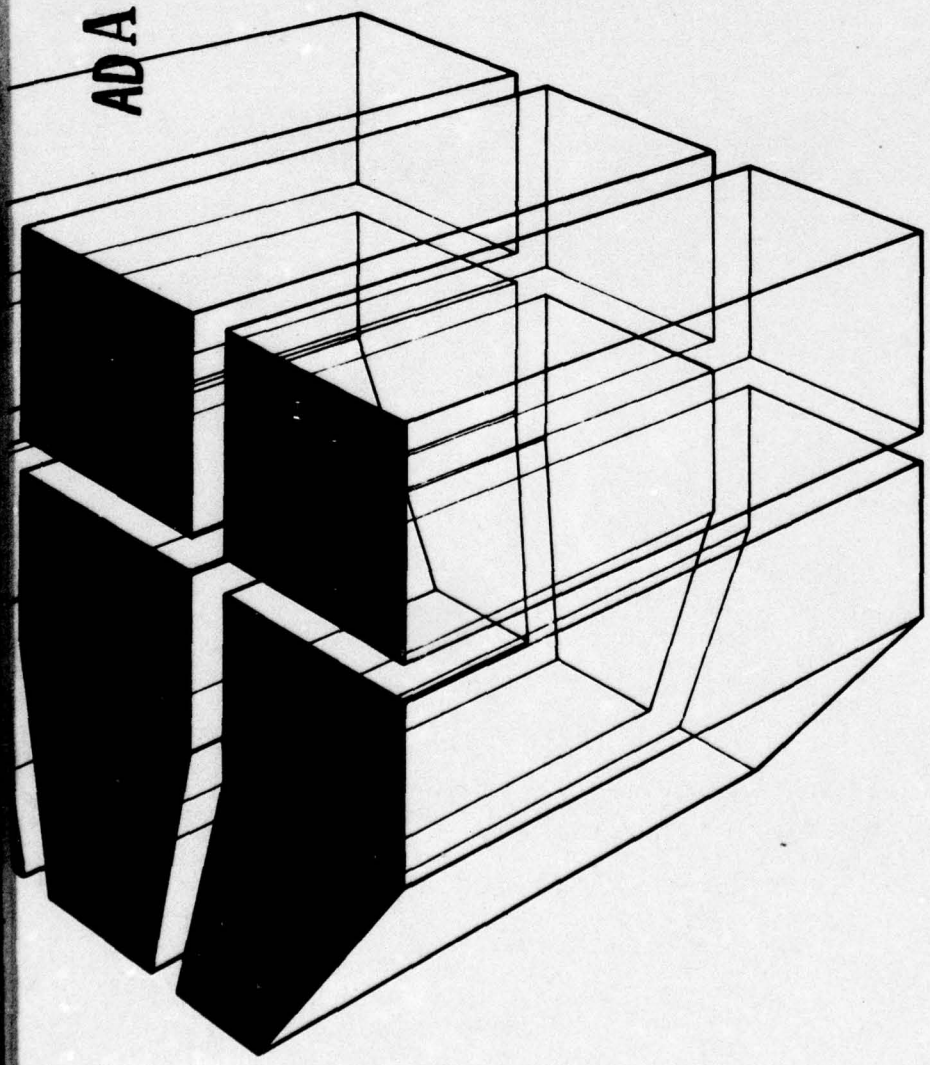

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents structural design criteria recommendations for theater of operations (T/O) temporary glued-laminated timber highway bridges. The report consists of two volumes: Volume I provides the design criteria, procedures, and material specifications, and Volume II contains the development of and justification for the criteria in Volume I.

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State-of-the-art methodologies were used to develop the criteria, which are based on modifications to existing military and permanent criteria. Use of the criteria by engineers in bridge design offices should result in T/O bridges that have adequate safety and perform satisfactorily.

Material weight of glued-laminated timber stringers in T/O bridges designed using the recommended criteria, typically will be about 15 percent less than when designed using permanent bridge criteria.

FOREWORD

This study was conducted for the Directorate of Facilities Engineering, Office of the Chief of Engineers (OCE) under Project 4A763734DT34, "Development of Engineer Support to the Field Army"; Task 04, "Base Development"; Work Unit 002, "AFCS Design Parameters for T/O Material Applications."

Mr. R. H. Barnard was the OCE Technical Monitor.

The research was conducted by the Construction Materials Branch (MSC) of the Materials and Science Division (MS), U.S. Army Construction Engineering Research Laboratory (CERL). Dr. L. I. Knab was Principal Investigator for the project. Mr. P. A. Howdyshell is Chief of MSC and Dr. G. R. Williamson is Chief of MS.

Contractors contributing to the study were R. C. Moody of the U.S. Department of Agriculture Forest Service, Forest Products Laboratory, Madison, WI and W. W. Sanders, Jr. and H. A. Elleby of the Iowa State University Department of Civil Engineering, Ames, IA.

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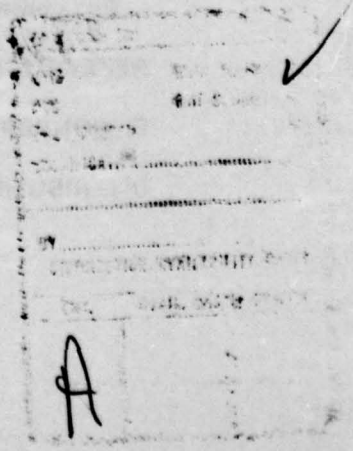

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RECOMMENDED DESIGN CRITERIA FOR GLUED-LAMINATED TIMBER HIGHWAY BRIDGES IN THEATERS OF OPERATION

1 INTRODUCTION

Background

Engineer troop units in the theater of operations (T/O) are assigned diverse construction missions which often have critical completion date requirements. Many of these missions involve erection or assembly of standard prefabricated components such as those available for buildings and tactical bridges, while others require construction using conventional materials and components.

The Army Facilities Components System (AFCS) contains standard designs for many structures that T/O troop units may be required to construct. The AFCS publication TM 5-302,[1] and its related logistical references TM 5-301[2] and TM 5-303,[3] contain many standard structural designs using both standard and prefabricated components, along with bills of materials and construction practice guidance. These manuals greatly reduce the planning and design effort required to complete a construction assignment.

However, design criteria for military bridges using glued-laminated timber are currently unavailable. Since the design life of T/O structures is typically from 2 to 5 years, use of civilian structural design codes, which are generally based on a 50- to 75-year design life and relatively high levels of reliability, can result in unnecessarily conservative and uneconomical designs for the limited performance needs of T/O structures.

Objective

The objective of this study is to develop design criteria recommendations for glued-laminated timber members in T/O highway bridges subjected to dead plus static live loads. The types of glued-laminated timber to be considered are those specified by American Institute of Timber Construction (AITC) Specification 117-74[4] and Product Standard (PS) 56-73,[5] which cover glued-laminated timber fabricated from Douglas fir, Western larch, Southern pine, and California redwood.

Approach

Appropriate reliability models were developed to analyze and evaluate the safety levels and consistency of existing permanent structural design criteria for glued-laminated timber bridge members. The models were then used to develop recommended T/O bridge design criteria for glued-laminated timber members for the dead plus live static load case.

Chapter 2 summarizes the development of the design criteria (the development and justifications for the criteria are detailed in Appendices A through E of Volume II). Chapter 3 presents the recommended design criteria, and Chapter 4 provides a design example. Chapter 5 presents the conclusions and recommendations.

2 SUMMARY OF DESIGN CRITERIA DEVELOPMENT

This report presents a rational basis for developing consistent design criteria for short-life structures. "Consistent" means that the probability or chance of reaching a limit state (limit state probability) of a structural member is compatible with the other limit state probabilities of that member or other members.

Member-resistance and structural loading data were combined to determine existing and recommended limit state probabilities and their corresponding safety index values. First order reliability theory and best estimates of central tendency (average values) coupled with measures of dispersion (coefficients of variation) of the resistance and load were used to compute the safety index values. These safety index values were computed for permanent and temporary structural elements and used as guides in determining recommended allowable stresses for the static failure mode. Recommended criteria for temporary bridges were determined to

[1] *Army Facilities Components System (AFCS)—Design*, TM 5-302 (Department of the Army, 1973).

[2] *Army Facilities Components System (AFCS)—Planning*, TM 5-301 (Department of the Army, 1973).

[3] *Army Facilities Components System (AFCS) Logistic Data and Bills of Materials*, TM 5-303 (Department of the Army, 1973).

[4] *Standard Specifications for Structural Glued Laminated Timber of Douglas Fir, Western Larch, Southern Pine, and California Redwood*, AITC 117-74 (American Institute of Timber Construction [AITC], 1974).

[5] *Voluntary Product Standard PS 56-73 for Structural Glued Laminated Timber* (AITC, 1973).

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yield safety index values which will provide adequate safety relative to the safety levels and performance of permanent bridges, while reflecting the bridges' temporary nature.

It was assumed in the criteria development that adequate fabrication, assembly, and erection procedures are used. Special provisions and criteria are recommended when lower quality fabrication, assembly, and erection practices are likely to occur.

Stringer weight savings of about 15 percent result from using the recommended T/O bridge design criteria rather than using the permanent bridge allowable stresses with the design procedures in Chapter 3.

3 RECOMMENDED DESIGN CRITERIA FOR AFCS BRIDGES

Scope

The following criteria are recommended for use in designing temporary T/O bridges using glued-laminated timber. Temporary bridges have design lives of 2 to 5 years (bridges whose failure would have unusually severe consequences are not considered temporary, even though their design lives may be 2 to 5 years). The maximum deviation from these criteria shall not exceed 2 percent (on the unconservative side) of the indicated design requirements.

The following criteria are based on AITC 117-74, PS 56-73, and the 1973 *National Design Specification (NDS) for Stress Grade Lumber and Its Fastenings,*[6] except as modified herein. The criteria apply to highway bridges only; they do not apply to railroad bridges.

Safety, Savings, and Cost Effectiveness

In the past, increased allowable stresses for static loading have been permitted for temporary steel stringer bridges.[7] The safety levels corresponding to the allowable stresses and/or design procedures for temporary glued-laminated stringer bridges were evaluated and used to determine acceptable design criteria and procedures which reflect the temporary nature of T/O bridges. The safety levels corresponding to the recommended criteria for T/O bridges loaded with their normal or maximum loads are comparable to or exceed those corresponding to permanent civilian bridges loaded with their maximum loads. However, the safety levels corresponding to the recommended criteria for T/O bridges loaded with their normal or maximum loads are below those corresponding to permanent bridges loaded with their normal loads. In summary, the recommended criteria should result in acceptably safe temporary bridges compared with current permanent civilian bridges loaded with their maximum loads.

This discussion of safety is based on the assumption of adequate fabrication, assembly, and erection practices; the safety of a bridge can be reduced significantly by low quality fabrication, assembly, and erection practices (see the **Fabrication, Assembly, Erection, and Handling** section of this chapter).

Material weight of glued-laminated timber stringers in T/O bridges designed using the recommended criteria will typically be about 15 percent less than when designed using permanent bridge allowable stresses with the procedures recommended in this chapter.

Use of the recommended criteria rather than the permanent criteria to prevent static failure will be cost effective if the material, transportation, labor, and storage cost savings exceed the cost of implementing the criteria (see the **Implementation** section of this chapter).

Use of the recommended criteria appears reasonable, provided that the temporary steel and timber bridges used in the past have been acceptably safe and have performed satisfactorily. The decision to use the recommended criteria is to be made by the AFCS Office at the Office of the Chief of Engineers (DAEN-FEE-A).

Implementation

The recommended criteria are based on modifications to existing (AITC 117-74 and 1973 NDS) allowable stresses for permanent structures. The recommended criteria require use of the military design loads and procedures (as opposed to allowable stresses) given in TM 5-312 and modified herein. Hence, the recommended criteria are intended for use by bridge design offices, and not by combat engineers in the field. The criteria "package" required

[6] *National Design Specification for Stress Grade Lumber and Its Fastenings* (National Forest Products Association, 1973).

[7] *Military Fixed Bridges,* TM 5-312 (Department of the Army, December 1968), with changes 1 and 2.

by a bridge design office would consist of these criteria (Chapter 3), which in turn require the use of modified TM 5-312 design loads and procedures and the modified AITC 117-74 and 1973 NDS allowable stresses.

Fabrication, Assembly, Erection, and Handling

The recommended criteria are based on the assumption that fabrication, assembly, and erection quality and tolerances are comparable to those used in U.S. permanent construction. The recommended allowable stresses shall be reduced accordingly for low quality fabrication, assembly, or erection. Fabrication, assembly, and erection shall be in accordance with AITC 117-74 and the AITC *Timber Construction Manual.*[8] Necessary precautions, including provision of adequate support and bracing to protect against buckling and other erection problems, shall be taken during erection.

Handling precautions shall be taken, especially for laminations which will be subjected to tension* during service. Notching the bottom of stringer ends *(e.g., to lower the elevation of the roadway)* shall not be permitted.

Serviceability

Because the criteria recommendations are based on limit state strength only, serviceability requirements, including deflection, are *not* covered by the criteria; they shall be imposed as judged necessary.

Preservative Treatments

In warm, moist areas, preservative treatment may be necessary to insure a 5-year life for members in ground contact, e.g., abutments, pilings, etc. If preservative treatment is not feasible, consideration should be given to specifying all heartwood decay-resistant species.**

Loads, Moments, and Forces†

The recommended criteria apply to the dead plus live load case (vehicle plus payload weight). Other loads, including wind, water, ice, and earthquake, are not covered.

The procedures given in TM 5-312 for determining the design loads and the moments and forces used in the design of bridge members and fastenings shall be used, except as modified herein.

The two load cases used in the design process—the *normal* vehicle crossing load case and the *caution* crossing load case—are described in Table 4-3 of TM 5-312. Normal crossings are convoy(s) consisting of vehicles not exceeding the posted bridge class. A caution crossing consists of a single line of vehicles crossing a one- or two-lane bridge on the bridge centerline. Each vehicle is spaced at 150 ft* or more and shall not be more than 1.25 times the normal posted bridge class. Additional details are given in Section IV, Chapter 4, of TM 5-312 and Paragraph 2-54 of FM 5-36.[9]

The current procedure in TM 5-312 proportions all members, fastenings, and connections on the basis of the normal class loading. The following recommended procedure, however, requires that they be proportioned on the basis of either the normal or caution load cases, as specified.

Flexural Members and Flexural Splices—Designing for Bending or Lateral Buckling in Stringers

The live load moments corresponding to normal class crossings found in Appendix D of TM 5-312 shall be used to proportion the flexural members or flexural splices for bending and lateral buckling.

The current procedure for stringer design given in Paragraph 6-5 of TM 5-312 shall be used, except that the recommended formulas in Table 1 shall be used to determine the effective number of stringers.

Shear in Stringers, Bearing Forces at Stringer Ends, and Forces in Stringer End Connection Fastenings

The live load shear force in stringers, bearing forces at ends of stringers, and forces in stringer end connection fastenings shall be determined by using the larger force resulting from the normal or caution

[8] *Timber Construction Manual,* 2nd ed. (AITC, 1974).

*Typically, the bottom laminations in stringers.

**For more information see "Decay Resistance," *Wood Handbook: Wood as an Engineering Material,* Forest Service Agricultural Handbook No. 72 (Department of Agriculture, Forest Products Laboratory, 1974).

†In certain cases, unrealistically low loads, moments, and forces can result if the current procedures in TM 5-312 are used.

*SI conversion factors for all units of measurement used in this report are given at the end of the report.

[9] *Route Reconnaissance and Classification,* FM 5-36 (Department of the Army, May 1965).

Table 1

Recommended Equations and Current TM 5-312 Equations for Determining the Effective Number of Stringers

Current TM 5-312 Equations		Recommended Equations
Single lane: $N_1 = \frac{5}{S_S} + 1$	(Eq 6-7a)	Single lane: $N_1 = c[\frac{5}{S_S} + 1]$
Two lanes: $N_2 = \frac{3}{8} N_S$ or $N_2 = N_1$ whichever is smaller	(Eq 6-7b)	Two lanes: $N_2 = c[\frac{3}{8} N_S]$ or $N_2 = N_1$ whichever is smaller

where N_1 = effective number of stringers for single-lane bridges
S_S = center-to-center stringer spacing in feet
N_S = number of stringers
N_2 = effective number of stringers for two-lane bridges
c = reduction factor given in Table 2

Table 2

Values of Reduction Factor c* Used in Recommended Formulas (Table 1) for Determining the Effective Number of Stringers

Bridge Deck Type	Ratio of Bridge Floor Width (out-to-out) to Bridge Span Length (W/L)	
	W/L ≤ 1.0	W/L > 1.0
Glued-laminated timber or concrete	1.0	0.75
Nailed-laminated timber, plank, or multiple-layered	0.90	0.70

*The factor c accounts for the reduction in lateral load distribution when using nailed-laminated timber, plank, or multiple-layered decks and/or bridges which are very wide compared to their span length.

crossing load cases. The shear for single-lane bridges is based on the caution load case; for two-lane bridges it is based on either the normal load case or, if larger, the caution load case. The following procedure (revised Paragraph 6-6, TM 5-312) shall be used to determine the shear force in stringers, the bearing forces at stringer ends, and the forces in stringer end connection fastenings.

6-6.* Shear Check (Shear Design)

c. *Glued-Laminated Timber Stringer Bridges*

Compared to steel stringers, glued-laminated timber stringers are relatively lower in horizontal shear strength. Thus, shear can be critical in glued-laminated timber stringers, and the horizontal shear stress often controls the allowable design load, particularly for short spans.

*Paragraph 6-6b shall be retitled *Solid-Sawn Timber Stringer Bridges.*

(1) *Dead Load Shear.* The dead load shear per stringer is determined as for a steel stringer bridge using

$$v_{DL} = \frac{V_{DL}}{N_S} \qquad \text{(Equation 6-12)}$$

(2) *Live Load Shear.*

(a) *Effective shear per stringer, v'_{LL}, for glued-laminated timber stringers.* The effective live load shear per stringer, v'_{LL}, must account for the shear per stringer due to loads near the support as well as loads out on the span. It can be assumed that the wheel or track loads which are at or near a support will go directly into the stringer (with the deck assumed to act as a series of simple beams) and the loads which are out on the span will be distributed laterally in a manner similar to moment. The effective live load shear per stringer v'_{LL} in kips shall be determined from Table 3.

(b) *Design live load shear per stringer, v_{LL}, for glued-laminated timber stringers.* Tests with timber beams indicate that the shear failure will occur when a concentrated load is at some constant distance from the support, rather than when the load is just off the support, the location that produces maximum shear. This is caused by the concentrated load tending to compress the fibers, thus increasing the horizontal shear strength. When the load is moved off the support a distance of about the depth of the stringer, the optimum condition for shear failure exists. Thus, the value of the effective live load shear per stringer, v'_{LL}, should be reduced accordingly. The design live load shear per stringer, v_{LL}, in kips, is:

Table 3

Value of Effective Live Load Shear Force per Stringer, v'_{LL}

	v'_{LL} for Single Lane,* kips	v'_{LL} for Double Lane,** kips
Wheeled vehicle	$1.25[(0.5+\frac{S_s}{32})V_A+(\frac{V_{LL_W}-V_A}{N_1})]$	$(\frac{S_s-2}{S_s})V_A+(\frac{V_{LL_W}-V_A}{N_2})$
Tracked vehicle	$1.25(\frac{V_{LL_T}}{2})$	$(\frac{S_s-2}{S_s})V_{LL_T}$

where: V_{LL_W} = wheeled vehicle shear in kips as given in Appendices D-4 and D-7† of TM 5-312

V_{LL_T} = tracked vehicle shear in kips as given in Appendices D-5 and D-7† of TM 5-312

V_A = the heaviest axle load in kips as given in column 3† of Appendix D-1 of TM 5-312

S_s = stringer spacing in ft

N_1 = effective number of stringers for single lane given in Table 1

N_2 = effective number of stringers for double lane given in Table 1.

*The coefficient of 1.25 is used to adjust shear from normal crossing case to caution crossing case.

**For the double-lane case, v'_{LL} shall be computed for both single and double lanes and the larger value of v'_{LL} shall be used.

†*Entries in Appendix D-7 and column 3 of Appendix D-1 are given in tons and must be converted to kips.*

$$v_{LL}=(\frac{L-d}{L})v'_{LL}, \text{ but not less than } 0.75\,v'_{LL}$$

(Revised Equation 6-17)

where v_{LL} = design live load shear per stringer in kips

L = bridge span in ft

d = depth of stringer in ft

v'_{LL} = *effective live load shear per stringer* from Table 3.

(3) *Total Shear Per Stringer.* .The total design shear, v, for a glued-laminated timber stringer is:

$$v=v_{DL}+v_{LL}$$

where v = total design shear per stringer in kips

v_{DL} = dead load shear per stringer in kips

v_{LL} = design live load shear per stringer in kips.

The rest of the shear design procedure shall be the same as that given in subparagraphs (4) and (5) of Paragraph 6-6b, *Timber Stringer Bridges* of TM 5-312.

Columns, Compression and Tension Members, and Their Associated Fastenings and Connections

The forces in compression or tension members and their associated fastenings and connections shall be the larger of the forces produced by the normal or caution crossing load cases.

Impact

The procedure to account for impact (no increase) given in TM 5-312 shall be followed.

Allowable Stresses—Members

The allowable stress for members in temporary T/O bridges shall be found from

$$f=MF \qquad \text{[Eq 1]}$$

where f = allowable stress for members in temporary bridges

M = modification factor found in Table 4

F = AITC 117-74 allowable stresses for members for the dead plus live load case for 10 years of continuous or cumulative

Table 4

Recommended Modification Factor M

Resistance*	Value of M
Bending	1.35
Shear	1.15
Compression parallel to grain**	1.15
Compression perpendicular to grain	1.15
Column buckling	1.00
Tension parallel to grain	0.80

*Appropriate member moments and forces shall be determined as specified in the **Loads, Moments, and Forces** section.

**Applies to fully braced columns only, i.e., when buckling cannot occur.

loading; F shall include all NDS modifications of stresses (except load duration) including moisture content, size effect (for bending), lateral stability (for bending), buckling (compression members), and bearing.

Depending on the application, bridge stringers treated with an oil-base preservative and having a waterproof deck may be designed with dry-use stresses for bending and shear. However, wet-use stresses shall always be used for compression perpendicular to grain.

Criteria for Fastenings and Joints, and Other Criteria Not Covered Herein

Criteria for fastenings and joints, and other criteria not covered herein, shall be as specified by NDS for permanent bridges; a load duration of 10 years of continuous or cumulative loading shall be used.

Criteria for Bridges Having Unusually High Consequences of Failure

For bridges whose failure would have unusually severe consequences, the AITC 117-74 allowable stresses for 10 years of continuous or cumulative loading (i.e., for permanent bridges) shall be used for members, except that 70 percent of the AITC 117-74 allowable stress for tension* shall be used. Criteria for fastenings and joints and all other criteria (except allowable stresses for members) shall be as specified by NDS for permanent bridges; a load duration of 10 years of continuous or cumulative loading shall be used. Recommendations given in the **Loads, Moments, and Forces** section of this chapter shall be used.**

Modulus of Elasticity†

Modulus of elasticity values for deflection checks and column design shall be taken from AITC 117-74.

4 DESIGN EXAMPLE

The following example of the design of glued-laminated stringers for an AFCS bridge is based on the criteria given in Chapter 3. Additional references[10] commonly used in glued-laminated timber design for permanent structures are suggested.

Design of Glued-Laminated Timber Stringer Bridge

Design class 50, two-lane bridge, glued-laminated stringers, nailed-laminated timber deck, single 60-ft span, stringer timber: Southern pine 24 F-3 combination, dry condition of use.

*Refers to axial tension parallel to grain and not to tension due to bending.

**In certain cases, unrealistically low loads, moments, and forces can result if the current procedures in TM 5-312 are used.

†This section applies to temporary bridges and bridges having unusually high consequences of failure.

[10] *Glulam Bridge Systems Plans* (AITC, 1974); *Timber Construction Manual*, 2nd ed. (AITC, 1974); *National Design Specification for Stress Grade Lumber and Its Fastenings* (National Forest Products Association, 1973); and *Standard Specifications for Highway Bridges* (American Association of State Highway and Transportation Officials, 1973).

Procedure	*Remarks* (References refer to TM 5-312 unless otherwise noted)

1. *Design Loads (60-ft span)*

   a. *Dead Load*

$$W'_{DL} = X + L(Y + ZC)$$ Equation 6-1

$$W'_{DL} = 500 + 60[7 + 0.4(50)]$$ Table 6-1

$$W'_{DL} = 2120 \text{ lb/ft} = 2.12 \text{ kips/ft}$$

$$M_{DL} = \frac{W'_{DL}L^2}{8} = \frac{(2.12)(60)^2}{8}$$ Equation 6-2

$$= 954 \text{ kip-ft}$$

$$V_{DL} = \frac{W'_{DL}L}{2} = \frac{2.12(60)}{2}$$ Equation 6-3

$$= 63.6 \text{ kips}$$

   b. *Live Load*

$M_{LL_W} = 1235$ kip-ft — Appendix D-6

$M_{LL_T} = 1338$ kip-ft ← Controls — Appendix D-6

$V_{LL_W} = 89.5$ kips — Appendix D-7

$V_{LL_T} = 89.2$ kips — Appendix D-7

2. *Stringer Selection*

   a. *Effective Stringers*

For a class 50 two-lane bridge, the minimum width is 24 ft 0 in. Maximum stringer spacing is 6 ft 0 in. — Table 6-2

The minimum number of stringers (N_S) is

$$N_S = \frac{W_R}{S_S} + 1 = \frac{24.0}{6.0} + 1 = 5$$ Equation 6-5a

The effective number of stringers for a two-lane bridge (N_2) is

$N_2 = c[\frac{3}{8} N_s]$ or $N_2 = N_1$ — Table 1 in Chapter 3 of this report.

whichever is smaller

$N_1 = c[\frac{5}{S_s} + 1]$ — Table 1 in Chapter 3 of this report.

$c = 0.90$ — Table 2 in Chapter 3 of this report. The reduction factor c corresponds to $W/L < 1.0$ and a nailed-laminated timber deck.

$N_1 = 0.90[\frac{5}{6.0} + 1] = 1.65$

$N_2 = 0.90[\frac{3}{8}(5)] = 1.69$ or

$N_2 = N_1 = 1.65$

Use smaller of N_1 or N_2

Therefore: $N_2 = 1.65$

b. *Design Moment,* m

$m = m_{DL} + m_{LL}$ — Equation 6-9a

$m = \frac{M_{DL}}{N_s} + \frac{M_{LL}}{N_2}$

$m = \frac{954}{5} + \frac{1338}{1.65}$

$= 190.8 + 810.9$

$m = 1001.7$ kip-ft

c. *Required Section Modulus*

$S_r = \frac{m(12)}{f_b}$ — Equation 6-10

Allowable bending stress, f_b

$f_b = MF_b$ — Equation 1 in Chapter 3 of this report where M = modification factor in Table 4 and F_b = allowable AITC 117-74 bending stress (assuming adequate lateral support).

$M = 1.35$

$F_b = C_F(2400)$

F_b for Southern pine, 24F-3 combination, dry is:
$F_b = C_F(2400)$

$C_F = (12/d)^{1/9}$

C_F = size effect factor given in Section 903-F NDS.

d = depth of member, in.

To obtain an estimate of F_b and f_b assume

$C_F = 0.85$

Then $f_b = (1.35)(0.85)(2400)$

$= 2754$ psi $= 2.75$ ksi

The required section modulus based on f_b = 2.75 ksi is

$$S_r = \frac{m(12)}{f_b} = \frac{(1001.7)(12)}{2.75}$$

Equation 6-10

$= 4371$ in.^{3}

Trial Section:
b(width) = 10.75 in. (actual dimension)
d(depth) = 49.5 in. (actual dimension)

Also see table in AITC 117-74 titled "Structural Glued-Laminated Timber Section Properties"

$C_F = (12/49.5)^{1/9} = 0.85$

Therefore $f_b = 2.75$ ksi is correct
and $S_r = 4371$ in.^{3}

$$S = \frac{bd^2}{6} = \frac{(10.75)(49.5)^2}{6}$$

$= 4390$ in.^{3}

$S > S_r$

Therefore, trial section is adequate for bending, assuming adequate lateral support

3. *Shear Check*

a. *Dead Load Shear*

$$v_{LL} = \frac{V_{DL}}{N_s} = \frac{63.6 \text{ kips}}{5}$$

Equation 6-12

$= 12.7$ kips

b. *Live Load Shear*

$v_{LL} = (\frac{L-d}{L})v'_{LL}$, but not less than $0.75\, v'_{LL}$ — Equation 6-17 of TM 5-312 as revised in Chapter 3 of this report.

v'_{LL}, *Wheeled Vehicle, Single Lane:*

$$v'_{LL} = 1.25[(0.5 + \frac{S_s}{32})V_A + (\frac{V_{LL_W} - V_A}{N_1})]$$ — Table 3, Chapter 3 of this report.

$S_s = 6.0$ ft

$V_A = 40$ kips — Appendix D-1, Column 3

$V_{LL_W} = 89.5$ kips

$N_1 = 1.65$

$$v'_{LL} = 1.25[(0.5 + \frac{6.0}{32})40 + (\frac{89.5 - 40}{1.65})]$$

$= 71.9$ kips

v'_{LL}, *Wheeled Vehicle, Double Lane:*

$$v'_{LL} = (\frac{S_s - 2}{S_s})V_A + (\frac{V_{LL_W} - V_A}{N_2})$$ — Table 3, Chapter 3 of this report.

$N_2 = 1.65$

$$v'_{LL} = (\frac{6-2}{6})40 + (\frac{89.5 - 40}{1.65})$$

$= 56.7$ kips

v'_{LL}, *Tracked Vehicle, Single Lane:*

$$v'_{LL} = 1.25\,(\frac{V_{LL_T}}{2})$$ — Table 3, Chapter 3 of this report.

$V_{LL_T} = 89.2$ kips

$v'_{LL} = 1.25\,(\frac{89.2}{2}) = 55.8$ kips

v'_{LL}, *Tracked Vehicle, Double Lane:*

$$v'_{LL} = (\frac{S_s - 2}{S_s})V_{LL_T}$$ — Table 3, Chapter 3 of this report.

$S_s = 6.0$ ft

$$v'_{LL} = (\frac{6-2}{6})89.2 = 59.5 \text{ kips}$$

Use largest v'_{LL} for single and double lanes and wheeled and tracked vehicles; — Table 3, Chapter 3 of this report.

Therefore $v'_{LL} = 71.9$ kips

The live load shear then becomes:

$$v_{LL} = (\frac{60-(49.5/12)}{60})71.9$$ — Equation 6-17 of TM 5-312 as revised in Chapter 3 of this report.

but not less than 0.75(71.9)

$v_{LL} = 0.93(71.9) = 67.0$ kips

and 67.0 kips > 0.75(71.9) kips

Therefore, $v_{LL} = 67.0$ kips

c. *Total Design Shear*

$v = v_{DL} + v_{LL} = 12.7 + 67.0$ — Chapter 3 of this report.

$= 79.7$ kips

d. *Effective Shear Area*

$A_{v_r} = \frac{v}{f_v}$ — Equation 6-19

$f_v = MF_v$ — Equation 1, Chapter 3 of this report.

$M = 1.15$ — Table 4, Chapter 3 of this report.

For Southern pine, combination 24F-3

$F_v = 200$ psi — Allowable AITC 117-74 shear stress, $F_v = 200$ psi

$f_v = 1.15(200) = 230$ psi

$= 0.230$ ksi

$A_{v_r} = \frac{79.7}{0.230} = 346$ sq in.

A_v of b = 10.75 in.,

d = 49.5 in. section:

$A_v = \frac{2}{3}bd$ — Equation 6-20

$$A_v = \frac{2}{3}(10.75)(49.5) = 354.75 \text{ sq in.}$$

$A_v > A_{v_r}$ Shear O.K.

4. The deck must be designed and the actual dead load versus the assumed dead load checked; appropriate changes in section modulus and shear area, if necessary, must then be made. The deflection and lateral bracing must be checked, the fastenings and joints must be designed, and the bearing must be checked.

5 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Design criteria, procedures, and material specifications developed using state-of-the-art methodologies should result in adequate safety and performance for T/O glued-laminated timber stringer highway bridges. (Volume II presents the development and justification of the criteria.)

2. Bridge stringer material weight savings of about 15 percent result when using the recommended T/O bridge design criteria rather than using permanent bridge allowable stresses with the design procedures recommended in Chapter 3.

3. The criteria, design procedures, and material specifications are given in Chapter 3 for AFCS bridges. In Chapter 3, modified design loads and procedures given in TM 5-312 and modified AITC 117-74 allowable stresses are recommended. The recommendations in Chapter 3 for AFCS bridges are intended to be used by engineers in bridge design offices, and not by combat engineers in the field.

Recommendations

1. The design criteria, procedures, and material specifications given in Chapter 3 should be considered for use in the design of AFCS T/O bridges.

2. Consideration should be given to the development of procedures, criteria, and material specifications for the design of glued-laminated timber decks for T/O glued-laminated timber stringer bridges.

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Army Facilities Components System (AFCS)—Design, TM 5-302 (Department of the Army, 1973).

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Timber Construction Manual, 2nd ed. (AITC, 1974).

Voluntary Product Standard PS 56-73 for Structural Glued Laminated Timber (AITC, 1973).

SI CONVERSION FACTORS

1 ft	= 0.3048 m	1 kip-ft	= 1.3558 kNm
1 ft-lb	= 1.3558 Nm	1 ksi	= 0.69 kN/cm^2
1 in.	= 2.54 cm	1 sq in.	= 6.4516 cm^2
1 kip	= 4.448 kN	(°F −32) 5/9	= °C

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